PROCEEDINGS

OF

THE ROYAL SOCIETY.

"Report on the Expedition to Sahdol, Rewah State, Central India, to observe the Total Solar Eclipse of 1898, January 22." By W. H. M. CHRISTIE, C.B., M.A., F.R.S., Astronomer Royal, and Professor H. H. TURNER, M.A., F.R.S. Received May 25, 1898.

The Report is presented in three parts.
Part I is a joint Report by the two observers.
Part II is a separate Report by the Astronomer Royal; and
Part III is a separate Report by Professor Turner.

PART I.

1. This expedition was organised by the Joint Permanent Eclipse Committee of the Royal Society and Royal Astronomical Society, funds being provided from a grant made by the Government Grant Committee.

The Government of India made excellent arrangements for the party, and the Surveyor-General of India with the staff of his Department rendered great service in selecting a site, clearing the jungle, establishing a camp, erecting the instruments, and in giving every assistance in the observations, for all of which the observers desire to tender their thanks.

The observers are also indebted to the Great Indian Peninsular Railway, the Bengal and Nagpur Railway, and the East Indian Railway for great liberality in granting facilities and in making special arrangements for the safe conveyance of their instruments from Bombay to Sahdol.

2. *Personnel.*—The following persons took part in the expedition:—

W. H. M. Christie, M.A., F.R.S., Astronomer Royal.

H. H. Turner, M.A., F.R.S., Savilian Professor of Astronomy at Oxford.

Harold A. H. Christie, who gave the exposures throughout the eclipse for the Astronomer Royal.

The Royal Society is collaborating with JSTOR to digitize, preserve, and extend access to *Proceedings of the Royal Society of London.* www.jstor.org

It was originally proposed that Dr. A. A. Common, F.R.S., should also take part in this expedition, but he ultimately found that he was unable to do so, and Dr. Copeland, Astronomer Royal for Scotland, was invited by the J.P.E. Committee to go in his place. Dr. Copeland preferred, however, not to join any of the three other expeditions, but to establish himself independently.

3. *Itinerary.*—The observers left Marseilles in the Peninsular and Oriental steamship "Ballaarat" (R.M.S.), on Thursday morning, December 16, 1897, their instruments having been put on board this vessel in London ten days earlier. They arrived at Bombay on Monday morning, January 3, 1898, the weather during the voyage being excellent. After a few days spent in landing the instruments and arranging for their journey to Sahdol, they left Bombay on Friday evening, January 7, travelling direct to Sahdol by special arrangements courteously made by the G.I.P., East Indian, and Bengal and Nagpur Railways, and arrived at Sahdol in the early morning of Sunday, January 9.

4. *Selection of a Station.*—The J.P.E. Committee originally proposed for this expedition a station south of Poona, either near Karad on the S. Maratha Railway or near Jeur on the G.I.P. Railway, other expeditions occupying stations near Viziadrug on the coast, and Pulgaon on the Nagpur branch of the G.I.P. Railway.

The Surveyor-General of India having offered to give every assistance to the expeditions, appointed Major Burrard, R.E., to make all necessary arrangements, including the determination of exact local time and of the longitude and latitude of the station. Major Burrard selected Karad, in the Satara district, as the best station. Owing, however, to the outbreak of plague at that place, and its prevalence in the Bombay Presidency, it was finally decided, on the advice of the Bombay Government, to abandon this choice and to occupy a station at Sahdol, on the railway to the east of Pulgaon, connecting Katni and Bilaspur. As this site was in dense jungle, it was necessary to clear a considerable space for the camp, part of which was to be occupied by a party under Mr. Michie Smith, Government Astronomer at Madras. This clearing, the establishment of the camp, and the erection of piers and huts for the instruments and of a dark room for photography, were all admirably carried out by Major Burrard, R.E., and his assistant, Lieutenant Crosthwait, R.E., before the arrival of the observers, who thus found everything ready for the setting up of their instruments.

5. *Position of Station.*—The observing station was about three-quarters of a mile from the railway station, on the south side of the line. The position of the centre of the pier on which the cœlostat used by the Astronomer Royal was mounted is—

Longitude 81° 21′ 33″ E. = $5^h\ 25^m\ 26^s{\cdot}2$ E.
Latitude 23° 16′ 45·3″.
Height above mean sea level 1502·4 feet.

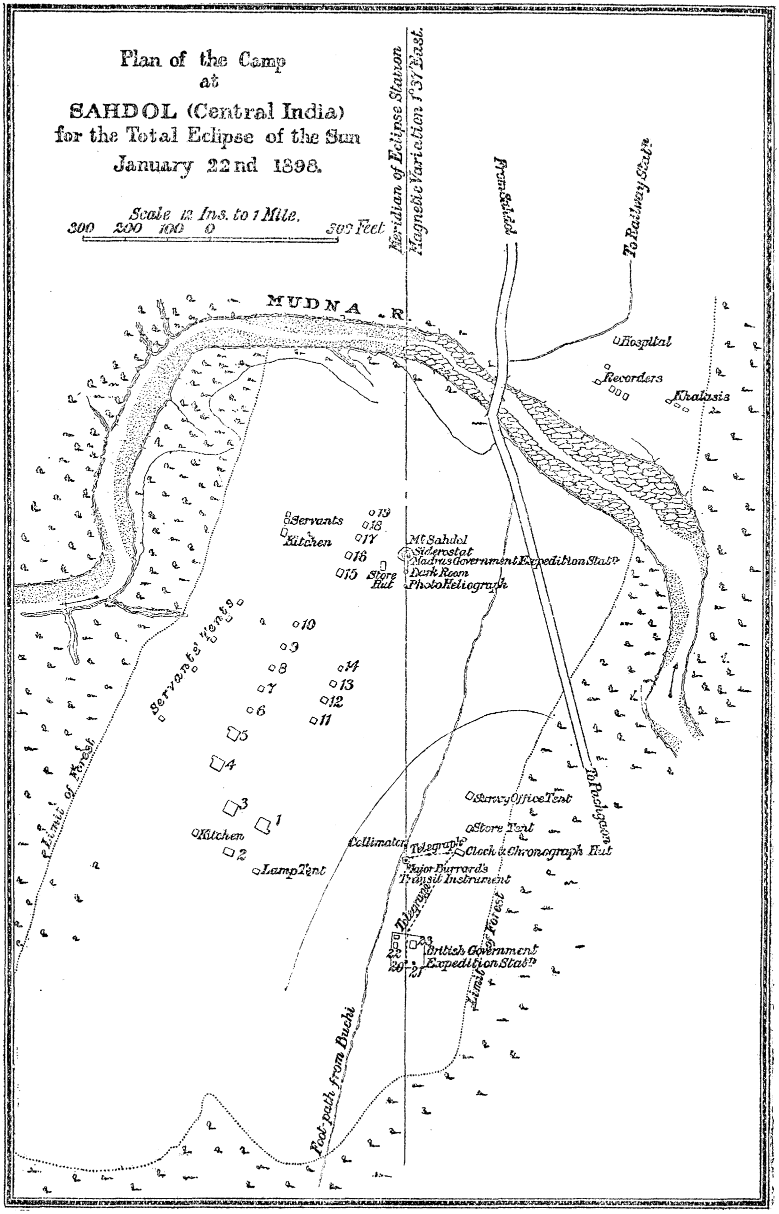
This position was determined after the eclipse by Major Burrard, R.E., by accurate triangulation, connecting the site with the principal triangulation of the Survey of India.

Professor Turner's cœlostat was 20 feet due east of this, and the transit instrument (used by Major Burrard in his time determinations) 240 feet due north of it.

This spot is 4 miles towards the south-east from the central line as shown in the 'Nautical Almanac' and 'American Ephemeris,' 3¼ miles from the line as shown in the 'Connaissance des Temps,' and 2 miles from the line as shown in the 'Berliner Jahrbuch.' It may be remarked that the data for predicting the four contacts given in the 'Nautical Almanac Circular No. 16' were found insufficient, the nearest points for which approximate formulæ were given being in longitude 79° (Nagpur) at a considerable distance from the central line, and in longitude 83° (south of Benares), too far away to give accurate predictions. [See Professor Turner's separate Report.]

6. *The Camp.*—The general arrangements of the camp (see next page), which consisted of more than fifty tents and huts, were, as already mentioned, admirably carried out by Major Burrard, R.E., it being necessary to clear a considerable space (about 700 by 300 yards) in the jungle by burning and felling trees, in order to set up the numerous tents of the living camp at some distance from the observing huts. On part of this clearing the Government Astronomer at Madras (Mr. Michie Smith) and his assistants erected their camp and instruments, and Major Burrard rendered considerable assistance to this party. There were also several tents for occupation by distinguished officers of the Survey, and we had the pleasure of seeing at the camp on the day of the eclipse the Surveyor-General (General Strahan, R.E.), General Woodthorpe, R.E., Colonel Sir T. Holditch, R.E., and other officers, and for a few days preceding the eclipse Colonel Gore, R.E., who left us for the Pulgaon Camp on January 19.

7. *Meteorological Conditions.*—From valuable information collected by Mr. Eliot, Meteorological Reporter to the Government of India, it appeared that the chances of fine weather were practically the same all along the line of totality, there being very little risk of cloud, though some chance of dust interfering with the definition. The thickly wooded country round Sahdol seemed well adapted for protection from the danger of dust, and during the days near the eclipse the ground near the instruments was covered with straw and watered in the morning to prevent excessive heating of the air in the



REFERENCE.

1. Mr. W. H. M. Christie, C.B., F.R.S.
   Master Harold Christie.
2. Lieut. H. L. Crosthwait, R.E.
3. Mess.
4. Professor H. H. Turner, F.R.S.
5. Major S. G. Burrard, R.E.
6. Mr. C. H. McA'Fee.
7. Mr. R. George.
8. Captain E. D. Bullen, R.E.
9. Colonel Sir T. H. Holditch, K.C.I.E., C.B., R.E.
10. Captain J. A. Dealy, R.E.
11. General C. Strahan, R.E.
    Colonel St. G. C. Gore, R.E.
12. General R. G. Woodthorpe, C.B., R.E.
13. Mr. C. Michie Smith.
14. Captain W. Ewbank, R.E.
15. Mr. A. H. Campbell, I.C.S.
    Surgeon-Major J. L. Van Geyzel, I.M.S.
16. Madras Mess.
17. Doctor J. W. Evans.
18. Mr. F. W. Lawrence.
    Mr. A. F. N. Moos.
19. Mr. R. Ll. Jones.
    Mr. H. Kelsall Slater.
20. Mr. Christie's cœlostat
    Lat. 23° 16′ 45″·3 N.
    Long. 81° 21′ 33″·0 E.
    Height 1502·4 feet.
21. Professor Turner's cœlostat.
22. Dark room.
23. Instrument tent.

path of the rays from the sun to the cœlostats, which were placed at a height of only 2 feet 8 inches from the ground.

The character of the weather was practically uniform during our stay at Sahdol. At night the minimum temperature was about 32° up to January 20, afterwards a little warmer (not falling below 39°, on January 23 and 24). At about 7.30 A.M., soon after sunrise, the temperature began to rise rapidly, attaining a maximum of about 80° at about 2 P.M., and remaining near this point from noon till about 4.30 P.M., when a fall nearly as sudden as the rise began. The air was nearly saturated with moisture at night and very dry in the daytime. There was heavy hoar frost at night.

These conditions seriously limited the time available for photography, which could only be carried on conveniently during the hot part of the day, say from 10 A.M. to 6 or 7 P.M., as there was no ready means of warming the water in the dark room.

The first clouds seen since the party landed in India were light fleecy clouds in the evening of Wednesday, January 19, and more appeared in the early mornings of January 20 and January 21, dispersing in each case between 10 and 11 A.M. The day of the eclipse was perfectly cloudless throughout, and the definition good.

[For detailed readings of thermometers and barometer, see separate Report by Professor Turner.]

8. *Instruments, &c.* [See separate Reports of the observers.]

9. *Huts.*—The chances of rain being so small, waterproof huts were not considered necessary, and the instruments were protected by rush thatchings laid on a framework of bamboo, which could be readily removed as required.

10. *Assistance.*—The observers were assisted in the exposures as below:—

The Astronomer Royal—	
Mr. McA'Fee............	Recorded times of exposure.
Mr. Harold Christie......	Exposed at objective.
Vishnoo Babaji Garnd....	Handed plates.
Venayek Narayan	Received plates.
Professor Turner—	
Dondu Venayek.........	Exposed at objective.
Tukaran Hanmant.......	Handed plates.
Shankar Devidas	Received plates.
Also	
Govind Balwant Joshi....	Counted seconds aloud.
Narayan Vishnoo Apte....	

A few seconds before totality, as shown by the diminishing crescent of the sun, Professor Turner was to call "Get ready"; at totality to call sharply (the monosyllable "Tup" was used). The first timekeeper immediately started the stop-watch and proceeded to count aloud "one, two, three," &c., up to sixty, when the second timekeeper took up the counting, "one, two, three," &c. By having two timekeepers, opportunity was given to both to see the eclipse.

The operations were rehearsed on every day of the week preceding the eclipse, at the time of totality, and on two days also at dusk, with lamps.

A photographic hut with a supply of chemicals was supplied from the Calcutta office of the Surveyor-General's Department, and Mr. George, of that department, was told off to assist in the photographic work. He developed some of the photographs taken by the Astronomer Royal during the partial phases.

11. *The Day of the Eclipse.*—Perfectly clear throughout. The morning was spent in final preparations. The first contact occurred at 0 hr. 13·3 mins. local mean time, and the Astronomer Royal proceeded to take nine photographs of the partial phase, the first being exposed at 0 hr. 14·6 mins., and the last at 1 hr. 22·2 mins. Totality commenced at 1 hr. 41·1 mins., and lasted about 105 seconds, during which time the programmes detailed below were successfully carried out. Nine more partial phase photographs were taken between 1 hr. 59·4 mins. and 2 hrs. 59·2 mins. The fourth contact was at 3 hrs. 1·6 mins. (see accurate times below).

There was a good deal of light during totality, and lamps were not in any way needed. The temperature fell 4·5° between first and second contacts, and another 3·5° between second contact and 2 hrs. It had practically returned to its normal value by the fourth contact (see accurate readings below). But the fall of temperature did not nearly represent the sensation of chill. At 1.15, when the air felt distinctly chilly, the temperature had only fallen 2°.

There was no appreciable "shadow" effect at totality, nor was any such effect noticed by two observers (General Woodthorpe, R.E., and Colonel Sir T. Holditch, R.E.) from the top of a hill a few miles away, close to the central line. These observers did, however, notice the well known "shadow bands" on the table they had prepared for sketching, without having previously heard of these bands in any way.

We had not many opportunities of observing the behaviour of animals. Kites which had been circling round the camp flew off to the surrounding trees some minutes before totality, and about the same time we heard cries from the village of Sahdol. We were told by another observer (Professor E. G. Hill, of Allahabad) that at Buxar he had noticed a herd of goats get into line and march homewards; that two mongooses in a hole in a bank had seemed very much frightened; that squirrels were silent during totality, and that a kingfisher began catching fish.

PART II.—SEPARATE REPORT BY MR. W. H. M. CHRISTIE.

The programme of observation was composed of two distinct parts—(1) Photographs of the corona on a large scale during totality; (2) photographs of the partial phase before and after totality for determination of the position of the moon relatively to the sun.

The instrument used in both cases was the photographic telescope by Grubb, with object-glass of 9 inches aperture and 8 ft. 6 in. focal length (presented to the Royal Observatory by Sir Henry Thompson), to which a concave compound lens by Dallmeyer, of 3 inches diameter and 12 inches focus, had been fitted as a secondary magnifier, placed a short distance within the focus. This combination gave an image of the sun 4 inches in diameter, and a field (for full pencils) of nearly 10 inches diameter, so that the corona to a distance of one and a half radii from the Sun's limb would be included in the field. A cœlostat, specially designed by Dr. Common, carrying a plane silver-on-glass mirror of 16 inches diameter, made by him, was employed to reflect the rays into the Thompson coronagraph, which was firmly mounted on two brick piers, so as to point to the mirror at an angle of depression of about 10°, and to be placed in an azimuth of about 17° north of west for the day of the eclipse. The camera was furnished with eight plateholders, taking 12 × 10 in. plates, seven being reserved for use during totality, and the eighth fitted with a Thornton-Pickard instantaneous focal-plane shutter, to take photographs on $8\frac{1}{2} \times 6\frac{1}{2}$ in. plates during the partial phases, for determination of the moon's position.

The seven slides for photographs of the corona during totality were exposed as below, the exposures being given with a screen held

No.	Exposure.			Plate.	Developer.
	Beginning.	End.	Duration.		
	Secs.	Secs.	Secs.		
1	6	7	1	Ilford ordinary...........	Hydroquinone dilute.
2	12	17	5	Ilford rapid.............	,, ,,
3	24	34	10	,, ,, (backed)......	,, ,,
4	40	60	20	Rocket (backed)..........	,, ,,
5	67	75	8	,, ...	Eikonogen.
6	81	82	$\frac{2}{3}$	Ilford ordinary	Hydroquinone dilute.
7	89	91	2	Gazelle (dry collodion)....	,, ,,

in front of the object-glass by my son Harold, and the times, reckoned from the commencement of totality (2nd contact), being recorded by Mr. McA'Fee, of the Indian Survey Department.

It had been intended to use Hill-Norris dry collodion "Gazelle" plates for three of the slides (the fineness of grain as compared with gelatine plates giving them a marked advantage), but from trials made before the eclipse it was found that these plates were for some reason untrustworthy. I, however, thought it well to expose one of these plates, but the result is not satisfactory.

The sky was cloudless during the eclipse, and the programme was carried out without a hitch, with the aid of two native assistants of the Survey Department (Mr. V. B. Garnd and Mr. V. Narayen), who respectively handed me the slides and received them from me, and there was fifteen seconds to spare before the end of totality, the duration at Sahdol being 1 min. 45½ secs. as observed.

For the partial phase, nine photographs were taken between first and second contacts, and eight between third and fourth contacts, as well as a photograph for orientation (with double exposure) immediately before and after the eclipse. The aperture of the object-glass was reduced to 3 inches for these photographs, as it was found by trials before the eclipse that with the aperture thus reduced the exposure given by the Thornton-Pickard shutter set to its highest speed was satisfactory for the slow plates used (Thomas's lantern plates). The times of exposure were recorded on a chronograph, a key being pressed by me in the left hand at the same instant as the exposure was given by pressing a pneumatic ball in the right hand. The times of the fall of the shutter were also independently recorded by Mr. McA'Fee with a chronometer carefully compared with the transit-clock. All the arrangements for accurate local time, which was of vital importance for this part of the programme, and for determination of the longitude of the station by connection with the principal triangulation of the Survey of India, were most ably carried out by Major Burrard, R.E., and Lieut. Crosthwait, R.E. The position of my instrument, as found by them after the eclipse, was Long. 81° 21′ 33″ = $5^h\ 25^m\ 26^s{\cdot}2$ E., Lat. 23° 16′ 45·3″ N. Altitude above sea-level 1502·4 feet.

The coronagraph was carefully focussed before the eclipse by use of the method described in the Report of the Eclipse Expedition to Japan, 1896,* the image of an object (gauze net in the plane of the plate), being photographed by reflection normally from the plane mirror of the cœlostat. A special spare back for the plateholder was prepared with a hole covered with gauze net just above the centre, and one of the 12 × 10 in. plates being cut in two, one half was placed in the lower half of the plateholder and the reflected image photographed on it at different parts of the field, the source of light being a paraffin lantern. The adjustment to focus was made by moving the secondary magnifier, rings of paper placed between flanges on the adapter carrying the magnifier and its mounting giving the means of doing this with great nicety. By this method, in which the error from imperfect focus is doubled by the double passage of the rays through the telescope, it was found that a displacement of the magnifier through the thickness of a sheet of paper (0·005 inch), representing 1/20,000th part of the focal length, made a sensible difference. The focus was thus obtained with great accuracy, as is evidenced by the sharpness of the image on the photographs taken during the partial phase.

---

* 'Monthly Notices,' R.A.S., vol. 57, p. 105.

The photographs with exposures of 8 secs., 10 secs., and 20 secs. all show coronal structure up to the edge of the plate, the streamer in the S.W. being particularly bright. A hurried eye estimation made by me during the 20 seconds' exposure gave the extreme extension of this streamer as about two-thirds of the distance of Venus from the Sun's centre, or about $3\frac{1}{2}°$ from the limb. The field being necessarily limited by the diameter of the concave enlarging lens (3 in.), it would be desirable to have one made of larger diameter for future eclipses so as to allow of the use of larger plates.

A comparison of the whole series of photographs indicates a close correspondence between the coronal streamers and the prominences visible, this correspondence being particularly striking in the case of three prominences in the N.W. quadrant from which three coronal rays rise, arching over at a distance of about 7′ from the limb and uniting to form one component of the striking long double ray in that quadrant. Other prominences on the Sun's limb appear also to be associated with extensions of the corona. The form of the corona bore a closer general resemblance to those of 1886 and 1896 as photographed than would have been expected considering that the date of the eclipse was so much nearer the epoch of minimum sun-spots, and in this connection it may be noted that there were three important groups of spots on the Sun about the time of the eclipse, and that a series of magnetic disturbances of moderate amount were recorded at Greenwich just prior to the eclipse, from January 15 to 21 continuously, indicating an unusual state of magnetic activity in close correspondence with the solar activity as evidenced by the Sun spots.

Part III.—Separate Report by Professor Turner.

Instrumental Equipment.

1. *The Camera.*—The double camera used in the Fundium Expedition of 1893 by Sergeant Kearney, and taken out to Japan in 1896 without result. The tube is of wood, 6 feet long and 14 × 7 inches in section, divided by a partition into two tubes of 7 × 7 inches section. In one of these is placed the "Abney"* lens of 4-inch aperture and 62-inch focal length, giving an image of the sun 0·57 inch in diameter; in the other the photoheliograph objective No. 2 (used in *Transit of Venus* expeditions), of 4-inch aperture and 5-feet focal length, with a Dallmeyer secondary magnifier of 7½ inches focus placed 5 inches within the focus, and giving an image of the sun 1½ inches in diameter; the camera furnished with six plate-holders, each taking two plates of 160 × 160 mm. (as in use for the Astrographic Chart), both plates being exposed by a quarter-turn of one shutter.

2. *The Cœlostat.*—The camera was pointed to a 16-inch cœlostat, the mirror of which was made by Dr. Common, the mounting and clock by Mr. J. Hammersley from designs by Dr. Common.

3. *The Polariscope.*—On the tube, and pointing to the same cœlostat, was a polariscopic apparatus consisting of an ordinary slit spectroscope (and telescope), with an Iceland spar double image rhomb substituted for the ordinary prisms. The instrument in its normal state had been used by Mr. Maunder in the 1886 eclipse expedition for photographing the spectrum of the corona. It is fitted with two plate-holders. The dimensions are as follow:—

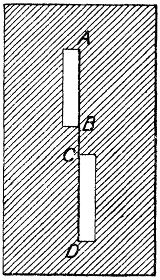
Objective......	3½	inches aperture,	18	inches	focal length.
Collimator.....	1½	,, ,,	6½	,,	,,
Camera........	2	,, ,,	9	,,	,,

The use of the apparatus will be understood from the analogy of the ordinary spectroscope, regarding the Iceland spar rhomb as a prism giving only two colours—the two kinds of polarised light. We can thus use a wide slit, opening it until the two images of the slit are just in contact without overlap. This was found to happen with the apparatus in use with a slit of width 0·19 inch. The diameter of the sun's image thrown on the slit being 0·21 inch, it was thought best to take the two photographs, so as to include opposite limbs of the eclipsed sun, and as much of the corona as could be got. The change from one portion of the sun to another was arranged by having two slits as follows:—

---

* One-half of a doublet photographic lens by Dallmeyer, belonging to Captain Abney, used in the Eclipse Expeditions of 1886, 1887, 1889, 1893, and 1896, acquired from him by the Royal Astronomical Society in 1893 for permanent use in eclipse expeditions, in consideration of their replacement by two others.

The two slits were cut in a piece of blackened card, the actual size of which is shown in the diagram. If the line ABCD had been diametral to the sun's or moon's image, half the moon and corona would in the first instance have appeared in the middle of the lower slit, CD. In this position the first exposure was given, producing on the plate two images side by side of the right limb of the eclipsed sun, one image being due to light polarised in a plane parallel to CD, and the other to light polarised in the perpendicular plane. For the next exposure the card was slipped down in the groove in which it fitted lightly, and the left limb of the eclipsed sun fell on the middle of the slit AB; and so two images of the rest of the corona would be obtained. By combining the two photographs, we could get a double picture of a slice of the corona 1·0 inch long and 0·40 inch wide, containing the moon centrally; or, translating inches into diameters of the moon's image, five diameters long and two diameters wide. As a matter of fact, the image of the sun was not adjusted centrally on the line ABCD, and a good deal more of the moon's disc appeared on one photograph than on the other, this being deliberately arranged for a special reason, which will appear in discussing the photographs obtained.



Instrumental Adjustments.

5. *Adjustment of Cœlostat.*—The adjustment of the polar axis was made as described in the Report on the Japan Expedition* by means of the attached declination theodolites.

The following are the actual observations, those with the level being made on the meridian, and compared with the known latitude so as to give the same sign to the errors as the sun observations:—

---

* 'Monthly Notices,' vol. 57, p. 102.

Date.	Sun's H.A.	Obs. decl.	Tab. decl.	O.—C.
Jan. 11....	−4·0	−21° 45′	−21° 50′	+5′
		Observation with level		+3
	(Adjusted in azimuth and altitude.)			
	−3·0	−21 50	−21 49	−1
		Observation with level		0
	−1·0	−21 49	−21 48	−1
Jan. 17....	−3·7	−20 47	−20 45	−2
		Observation with level		0

[These observations were made with a dummy axis, before the mirror and its cell were mounted on January 19.]

Jan. 21....	−3·0	Observation with level		+6

[Adjusted level: probably disturbed by the weight of the mirror and its cell.]

	−2·0	Observation with level		0
	−2·0	−19 54	−19 54	0

[As there seemed some vibration in the instrument, the end of the arc holding the mirror was supported by a wooden block driven tightly under it; this again altered the level, which was readjusted.]

	0·0	−19 51	−19 53	+2
	0·0	Observation with level		+2
	+2·0	−19 49	−19 52	+3
Jan. 22....	−4·5	−19 37	−19 42	+5
		Observation with level		+2
„ 23....	−1·0	−19 24	−19 26	+2
		Observation with level		+3

It will be seen that the introduction of the wooden block as a partial support to the cœlostat disturbed the adjustments slightly, but it did not seem advisable to attempt to correct these small errors, which would have been a troublesome process with the stress of the wooden block to consider. The block certainly deadened the vibrations.

6. *Tilt of Mirror.*—If the mirror is not parallel to the axis of rotation the image will not be quite stationary.* Both instruments were tested for this error by reversing the mirror and cell in the Y's and noting the consequent displacement of the sun's image on the ground glass in the focal plane of the telescopes. The displacement,

---

* 'Monthly Notices,' vol. 56, p. 417.

giving double the inclination of mirror to axis, was found by C. on January 19 to be 7·2′; and was corrected after several trials to be 0·8′, denoting an error of 0·4′. The correction was made by screwing a short screw, made for the purpose, into one of the holes at the back of the mirror cell. [There are three of these holes, into which long screws are screwed in the operation of inserting the mirror into its cell.] T.'s mirror was examined on the same day, and being found to be sensibly parallel to the axis, no correction was necessary.

7. *Focussing of Telescopes.*—The method adopted was that described in the Report on the Japan Expedition.* The telescope was pointed normally to the mirror, and the image of a bright point or object in the plane of the film was photographed on the film.

A glass plate being cut in two, one half was blackened with asphalte, and the word "astronomy" printed on it by scratching with a needle point. This was the object photographed in the following experiments. Gauges had been made in England by means of which the three lenses (the Abney lens, the photoheliograph lens, and the Dallmeyer enlarging lens) could be set very accurately to positions in the wooden tube giving good focus. Positions at definite distances from these could be obtained by unscrewing the object glasses through fractions of a turn. If positions were required *within* the gauge position, the object glass was first *pushed* in slightly; and then it was noted what fraction of a turn it must be unscrewed to bring it to the gauge-position. Designating the gauge-position by zero, and one turn out by +1·0, one turn inside by −1·0, the following positions were tried:—

Abney Lens.

Plate 1, January 16, 0·0, +0·5, +1·0 positions. Three images on same plate, 0·0 the best.

Plates 2—5 were devoted to experiments on illuminants. A candle was found most convenient after all.

Plate 6, January 16, 0·0, −1·0, −1·5 (+0·5) positions; (+0·5) not on plate? 0·0 the best, if exposures rightly identified.

Plate 7, January 16, −1·5, −0·5, +0·5 positions; −0·5 the best of these.

Plate 8 (January 16). To make sure pushed still further in.

The above differences were slight, −3·0, −2·0, −1·0 positions, −1·0 the best.

Hence on this day focus seems at −0·5, or very close to it.

---

* 'Monthly Notices,' vol. 57, p. 105.

Dallmeyer Lens and Enlarger.

Plate 9, January 16, −1·0, 0·0, +1·0, +2·0 positions; 0·0 the best.

Plate 10, January 16, −0·5, +0·5, +1·5 positions; +0·5 the best.

Plate 11, January 17, 0·0, +0·25, +0·5, +0·75, 0·0 positions. Both 0·0 exposures were worse than the others.

Of the others 0·25 was perhaps best near the centre, and 0·5 (or 0·75 ?) further from centre.

Hence 0·5 was adopted, *i.e.*, the object glass was screwed one-half turn out. The screw has 12 turns to the inch; and the focussing was thus correct to 0·02 inch, as far as could be judged.

Abney Lens—(continued).

Plate 12, January 17, −1·0, −0·5, 0·0, +0·5, +1·0 positions; −1·0 best; −0·5 very good; 0·0, +0·5, +1·0 distinctly inferior.

This contradicts nothing but plate 6, on which the exposures may be wrongly identified, and if on that plate 0·0 is missing instead of +0·5, then −1·0 would be the best on the plate. *Hence* −1·0 *was adopted.*

[At 25 turns to the inch this focus was also correct to 0·02 inch.]

8. *Programme of Observations.*—The six slides for photographs of the corona were filled as below, the same plates being used for the Dallmeyer and Abney lenses in each case, and standard squares having been impressed on plates 2, 4, 5, 6, by Captain Hills, R.E., before sending the plates out from England.

No. of slide.	Exposure.	Plate.
1	1 sec.	Dry collodion "Gazelle."
2	5 secs.	Ilford "Empress."
3	10 ,,	Rocket.
4	20 ,,	Ilford "Rapid."
5	1 sec.	Ilford "Empress."
6	2 secs.	Ilford "Empress."

Besides these the two exposures through the polariscopic apparatus were made, each of 5 seconds' duration, Paget plates being used.

The developer used was amidol for all these plates, which were all successfully exposed.

9. *Times of Contacts.*—These were independently observed by Professor Turner and by Major Burrard, R.E. The former used for first and fourth contacts a pocket watch which was compared with the sidereal clock at 8.5 A.M. and found 29 seconds fast; and again at 8 P.M., and found 26·9 seconds fast, of local mean time. At second and third contacts he gave a sharp signal, the time of which was

noted by Mr. McA'Fee on a mean time chronometer, carefully compared with the clock both before and after. The contacts were observed by throwing a 4-inch image of the sun on white paper from a navy-pattern telescope. [Aperture 2 inches, focal length 28 inches, magnifying power of negative eyepiece 25.]

Major Burrard observed with a 2-inch telescope, and recorded his times on the chronograph in connection with the sidereal clock.

This clock was in a grass hut and subjected to a daily variation of 50° of temperature, but great care was taken with the star observations, as will be explained in detail in the final report of the Astronomer Royal. The local mean times of the star observations for clock error (by Major Burrard) were

January 21 days 18 hrs. 30 mins. 58 secs., and January 22 days 7 hrs. 21 mins. 13 secs, and the errors of the clock at these times were, +0 min. 12·83 secs. and +0 min. 14·88 secs. respectively.

Local Mean Times of the Four Contacts.

Observer H.T.				Observer B.	Calculated time.	Calculated from 'N.A. Circular, No. 16,' with formulæ for	
						Nagpur.	Benares.
	hrs.	mins.	secs.	secs.	secs.	secs.	secs.
I.	0	13	11·7	22·8	6·3	11·3	8·8
II.	1	41	3·0	3·3	5·4	12·3	9·3
III.	1	42	48·5	47·9	52·0	67·3	49·3
IV.	3	1	40·2	35·7	51·3	63·7	45·3

10. *Remarks on Formulæ for Prediction of Contacts.*—As was mentioned in paragraph 5 of the joint report of the Astronomer Royal and Professor Turner, the data for predicting the four contacts were found insufficient. This will be seen by comparison of the last two columns, wherein the times as given by the published formulæ most nearly suitable for Sahdol are given. On application to the Superintendent of the 'Nautical Almanac,' he kindly supplied the data for the third column, giving the G.M.T.s of the four contacts, to which the longitude of Sahdol has been applied.

[The position of Sahdol is

5 hrs. 25 mins. 26·2 secs. E., Lat. 23° 16′ 45″ N.]

As his letter contains a suggestion which may be useful to other observers, I reproduce it here.

"Nautical Almanac Office,
"March 26, 1898.

"Dear Turner,

"You will find the deduction of the formulæ (used in 'N.A. Circular No. 16' and others) in appendix to N.A. 1836, p. 117. These equations will give sensible accuracy for a distance of about 50 miles from the point for which they are computed. In this case the distance is about 150 miles.

"I find that the most expeditious way of getting accurate results in this work, is to use the Besselian Elements (page 4 of circular No. 16). You can infer the time of middle of eclipse to the nearest minute from the Table on p. 3 of circular, and then 10 minutes work gives you the times of beginning and ending of totality with sensible accuracy.

"Of course for accurate determinations of times of first and last contacts (partial phase) special computations for the approximate times of these contacts would be necessary.

"Yours very truly,
"A. M. W. Downing."

The following remarks on the geometrical significance of these formulæ may not be out of place.

The time of a contact t at a place of geocentric latitude l and longitude λ is given by a pair of equations of this form

$$\cos \omega = A + B \sin l + C \cos l \cos (\lambda + D)$$

$$t = E + F \sin \omega + G \sin l + H \cos l \cos (\lambda + K).$$

Write these in the form

$$\cos \omega = A + L\{\sin l \sin l_0 + \cos l \cos l_0 \cos (\lambda - \lambda_0)\} = A + L \cos PP_0,$$

$$t = E + F \sin \omega + M \{\sin l \sin l_1 + \cos l \cos l_1 \cos (\lambda - \lambda_1)\}$$
$$= E + F \sin \omega + M \cos PP_1,$$

where P is the point (l, λ) and P_0 a point whose geocentric latitude and longitude are l_0 λ_0 given by the equations

$$C \tan l_0 = B = L \sin l_0, \qquad \lambda_0 + D = 0,$$

and PP_0 is the arc of the sphere between P and P_0.

Similarly for the point P_1.

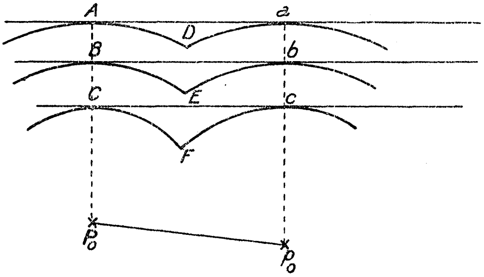
In the case of the second and third contacts, which determine totality, the equations only differ in the sign of F: so that the duration of totality is constant when ω is constant. The condition $\omega = 0$ gives us points for which the eclipse is just total for an instant, *i.e.*, the points on the borders of the totality belt. But from the equation

$$\cos \omega = A + L \cos PP_0$$

we see that ω is constant when the arc PP_0 is constant, *i.e.*, along the arc of a small circle described with centre P and radius PP_0.

The bounding lines of the totality belt given us by the approximate formulæ of the 'Nautical Almanac Circular,' are thus portions of small circles of the sphere.

Now, suppose we have formulæ given for the neighbourhoods of two points B and b on the central line; for which P_0 and p_0 are the centres of the approximate loci of equal totality. Then the approximate formulæ for B will give us as the northern boundary of the



totality zone the circular arc AD, touching the true line at A, but falling south of it elsewhere; and the approximate formulæ for b will give us the arc *ad*. Thus at the intermediate point D, both formulæ give errors in the same direction; and unless the points B and b are tolerably close together we cannot get a good prediction for intermediate points by simple interpolation.

The true lines A*a*, B*b*, C*c*, are the *envelopes* of such circles as AD, BE, CF, as we travel along the central line, P_0 travelling along the path P_0p_0 in correspondence.

It is to be noted further, that the approximate formulæ give a constant duration of totality along the line BE, which is the approximate central line (given by $\sin \omega = 1$): whereas the duration generally changes as we go east or west. But interpolation between results for B and b would probably give the means of allowing for this change.

If instead of the duration of totality, we take the time of one of the contacts, the approximate loci are no longer circles, but curves of the form

$$(a + b \cos PP_0)^2 + (c + d \cos PP_1)^2 = 1,$$

and the geometry is less simple; but these curves will have the true line for their envelope just as the circles did.

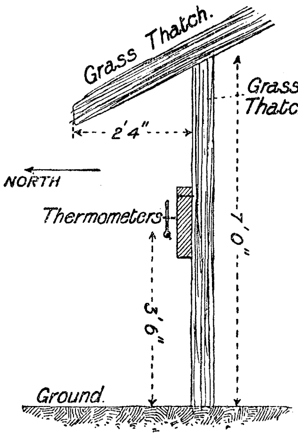
Now, if the contact of the circles or the curves with their envelope is of the *second order* interpolation becomes possible, for the circles cross the envelope and thus the error introduced is + to the east and — to the west. The test of this is to calculate the contacts for *b* with the constants given for B, and compare with true values for *b*; similarly calculate the contacts for B with the constants given for *b* and compare with the true values for B. If the errors are of opposite signs, then the curve crosses the envelope, and the contact is of the second order. A few experimental calculations of this kind, with the data of 'N.A. Circular, No. 16' seem to show, however, that the contact is not generally of the second order, and the approximations are thus subject to the disadvantages above indicated.

11. *Meteorological Observations.*—Lieut. Crosthwait, R.E., has kindly supplied the following particulars of the meteorological observations:—

They were made from 1898, January 14, to January 24 inclusive, by the following observers:—

Venayek Narayan, Narayan Vishnoo Apte, Govind Ramchandra Bhabhi, and Vishnoo Babaji Garnd.

The thermometers were attached to a board suspended to the north side of a grass hut, with an overhanging roof, completely shading them from the sun's rays at all times of the day. Height above ground and other dimensions shown in accompanying diagram.



The situation is open, facing towards the north, on a gently undulating plain, about 1500 feet above sea level. The only hills in the neighbourhood are from 2000—3000 feet high, distant about 12 miles.

The following instruments were used: A maximum and minimum thermometer No. 20,443 by Hicks; a wet and dry bulb No. 38,037 by Negretti and Zambra; a mountain mercurial barometer, standing on a tripod, No. 1824 by L. Casella.

Before beginning, the following comparisons were made with a standard thermometer No. 93,638 by Casella:—

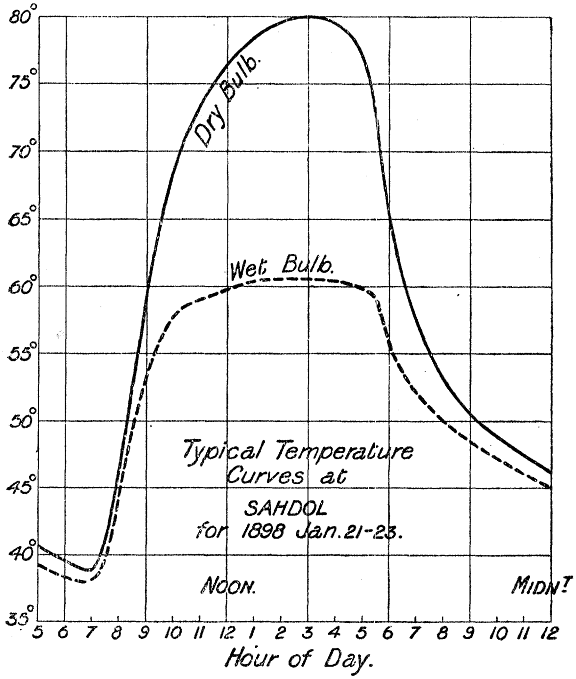
Standard read	78·6°		
Dry bulb ,, ...	77·9	correction	+0·7°
Wet ,, ,, ...	78·0	,,	+0·6
Maximum ,, ...	78·0	,,	+2·6
Minimum ,, ...	78·0	,,	+0·6

The wet and dry bulb thermometers, and the barometer with its attached thermometer, were read every half hour from 5 A.M. till 8 P.M. or later. The maximum thermometer was read at 4 P.M., the minimum at 10 A.M.

On the day of the eclipse, observations were made of wet and dry bulb and barometer, and also of the standard thermometer (Casella No. 93,638) every five minutes.

The barometer was very steady throughout our stay, near 28·6 in.; and it seems scarcely necessary to publish the details.

The wet and dry bulbs both followed very closely the curves shown in the attached diagram, the deviations from the curve seldom exceeding a degree or two. To avoid needless printing, the follow-



ing particulars for a number of readings on January 21, 22 and 23 are given as illustrations :—

Excess of Readings of Thermometers over the Typical Curves shown in the Diagram.

	Dry bulb.			Wet bulb.		
Hour.	Jan. 21.	Jan. 22.	Jan. 23.	Jan. 21.	Jan. 22.	Jan. 23.
6 A.M.	−1·9°	−1·3°	+1·1°	−1·6°	−0·6°	+0·8°
8 ,, ...	−1·4	+0·5	+2·0	−1·8	−0·3	+1·8
10 ,, ...	−1·5	+1·5	+2·8	−0·8	−0·6	+1·1
NOON	−2·6	+1·3	+1·9	−0·8	+0·2	+0·8
1 P.M.	−1·6	0·0	+2·0	−1·9	−1·0	+2·1
2 ,, ...	−0·8	−9·0	+1·0	−1·6	−3·5	+1·5
4 ,, ...	−0·6	−2·6	+0·4	−0·3	−0·5	+1·5
6 ,, ...	+3·0	−2·3	+1·1	+0·2	−0·6	−0·9
8 ,, ...	−1·6	−0·6	+2·0	−1·6	+0·1	+1·8
10 ,, ...	−1·9	+0·3	+2·3	−0·8	+0·6	+1·8

[The anomalous readings of dry bulb at 6 P.M. on January 21, and of wet bulb at 6 P.M. on January 23, are apparently not mistakes, unless the neighbouring observations are similarly affected.]

We may thus take it that the typical curves of the diagram represent with considerable accuracy what would have been the state of things on January 22, if the eclipse had not taken place.

Comparing then the readings during the eclipse with this curve, we get the following differences, which may be regarded as the effect of the eclipse.

Effect of the Eclipse on Temperature as shown by Five-Minute Readings.

Time of day.			
hrs.	mins.	Dry bulb.	Wet bulb.
0	0 (NOON)	+1·2°	−0·1°
0	5	0·0	−0·7
0	10	+0·8	−0·2
0	15 First contact	+1·7	+0·2
0	20	+1·5	+0·1
0	25	+0·8	−0·9
0	30	+0·6	−0·5
0	35	+0·4	0·0
0	40	+0·3	−0·1
0	45	+0·2	−0·1
0	50	−0·5	−0·2
0	55	−0·6	−0·4

Effect of the Eclipse on Temperature as shown by Five-Minute Readings—*continued.*

Time of day.				
hrs.	mins.		Dry bulb.	Wet bulb.
1	0		−1·3	−0·8
1	5		−1·9	−0·8
1	10		−2·0	−1·3
1	15		−2·2	−1·4
1	20		−2·8	−1·9
1	25		−3·4	−1·9
1	30		−4·0	−2·5
1	35		−4·0	−2·5
1	40	Totality	−5·1	−3·5
1	45		−7·2	−3·5
1	50		−7·7	−3·5
1	55		−8·3	−3·6
2	0		−8·9	−3·6
2	5		−8·5	−3·1
2	10		−7·6	−2·6
2	15		−6·7	−2·2
2	20		−5·7	−1·9
2	25		−5·1	−1·7
2	30		−4·4	−1·7
2	35		−3·4	−1·5
2	40		−3·7	−1·4
2	45		−3·5	−1·2
2	50		−3·5	−1·2
2	55		−3·1	−0·6
3	0	Last contact	−3·1	−0·6
3	30		−2·6	−0·3
4	0		−2·5	−0·2

"Total Solar Eclipse of January 22, 1898. Preliminary Report on Observations made at Ghoglee, Central Provinces." By Professor Ralph Copeland, Astronomer Royal for Scotland. Received May 10, 1898.

In the month of August, 1897, I was invited by the Joint Permanent Eclipse Committee to take part in observing the total solar eclipse which occurred in India on 22nd January of the present year.

The preparation of the equipment, which will be described further on, was at once proceeded with, and by the sanction of the University authorities and the Secretary for Scotland I was granted the